Estimating Vapor Density and Solubility

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Relative vapor density and water solubility of gases and vapors can be estimated with a simple field test. The test uses a visible fume mixed with the gas or vapor that is then released from a beaker. Lighter than air gases and vapors will rise from the beaker and appear to lift the "smoke" with it; heavier than air vapors will appear to drag the "smoke" downward. The most practical way to produce a visible "smoke" is by using an air flow indicator from a glass tube similar in appearance to a colorimetric air monitor tube.

Sensidyne, Inc. manufactures the Sensidyne Tube 5100 Smoke Tube (Air Flow Indicator Tube). The Sensidyne smoke tube contains stannic chloride that reacts with humidity in the air to form a visible white "smoke" containing hydrochloric acid mist and tin oxide fume. The "smoke" is designed to be approximately neutral buoyancy for use in tracing air currents, but in practicality it appears to be just slightly heavier than air. The stannic chloride tube can also be used in the Irritant Smoke Respirator Qualitative Fit Test Protocol (Occupational Safety and Health Administration, 29 CFR 1910.134).

Drager also manufactures the Air Current Detector Tube (CH 00216). The Drager tube contains iodine pentoxide, potassium permanganate and fuming sulfuric acid that produces a visible white fume when it contacts humidity in the air. The Drager fume appears to be slightly denser than the Sensidyne fume; the smoke fume will tend to slightly increase the relative density of the sample gas or vapor.

Additionally, Drager makes the Flow Check Air Flow Indicator (6400761). This handheld device uses a hot wire and a solution of long chain alcohols to produce a visible smoke similar to that produced by a theater smoke machine or smoke generators used in fire academy training. It is difficult to control the amount of smoke injected into the sample while keeping the observation area free of smoke. The vapor density of the partially combusted alcohol could not be confirmed.

You should practice the procedure first with room air and fume from the indicator tube you have on hand so you will notice any influence of the fume in the test. This will also allow you to determine if subtle room air currents are present. This test must be done in still air in a manner that protects the breathing zone of the operator. Ideally, you could do this near an exhaust fan that can be turned on to clear the air of gas, vapors and fume when they are eventually released from the beaker. Do not breathe the smoke fume directly.

Relative vapor density is affected by temperature, atmospheric pressure and humidity. Since this test is used to estimate relative vapor density in the field for immediate application, atmospheric pressure and humidity can be considered stable for the time of the test. Humid air is lighter than dry air because the molecular weight of water (about 18) is less than the average molecular weight of air (about 29). Expect heavier than air vapors to settle into low areas and be more persistent in humid conditions. Day-to-day variations in conditions at a site can affect relative vapor density.

Temperature is easily variable and it is important that the sample, container and air are the same temperature. Vapor that is warmed or cooled in the container relative to ambient air will markedly affect vapor buoyancy. Before testing the sample, determine the temperature of the bottom of the container with an infrared thermometer. Next, wave a sheet of paper through the air several times to assure the temperature of the paper and air is identical and then measure the temperature of the paper with the infrared thermometer. Proceed only when the temperatures of the container and paper are equal.

To perform the test, break the ends off an air flow indicator tube and insert one end of the tube into a rubber bulb. Test the fume production by squeezing the bulb once in the area of the test site. Observe the fume in air to assure the room air is still. The images below were made using Sensidyne Tube 5100 Smoke Tubes (Air Flow Indicator Tubes).

Add a few drops of liquid sample to the bottom of a 250 ml beaker (Figure 1), cover with a lid and roll the beaker to spread the liquid across the glass in a manner than maximizes the surface area of the liquid (Figure 2). If the sample is a gas, inject a stream of gas into a 250 ml beaker. Keep the top covered as much as possible with a lid, such as a watch glass or some flat, inert material in order to trap the vapor or gas. Insert the air flow indicator tube into the beaker through the spout while keeping the beaker covered as much as possible. Fully squeeze the bulb once and hold it; do not

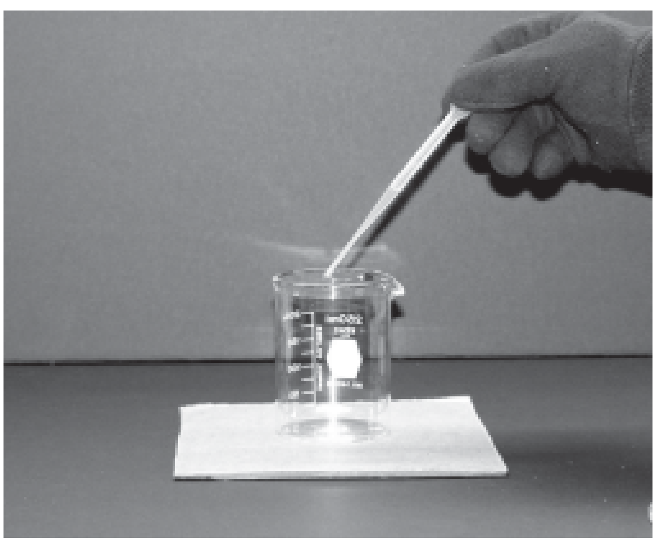

Figure 1. A few drops of liquid sample are added to a 250 ml beaker. Acetone (vapor density 2.0) is used in this sequence.

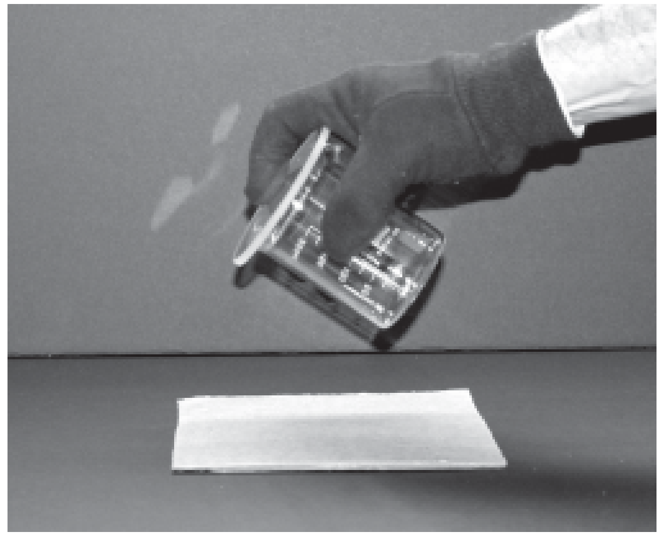

Figure 2. The liquid is rolled within the covered beaker to increase surface area and vapor production. Use an insulating glove to assure your hand does not heat the container and sample.

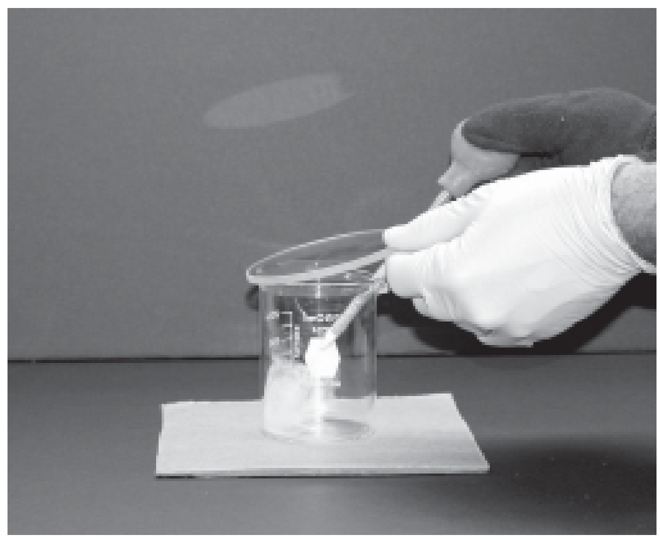

Figure 3. The vaporized sample is injected with fume from an air current tube. Do not allow the bulb to expand while the tube is in the beaker. This will prevent sample vapors from being diluted through both the movement of vapor into the tube and the subsequent movement of air into the beaker.

aspirate the vapor sample from the beaker into the tube (Figure 3). Gently center the cover on the beaker and allow the temperature of the sample to stabilize.

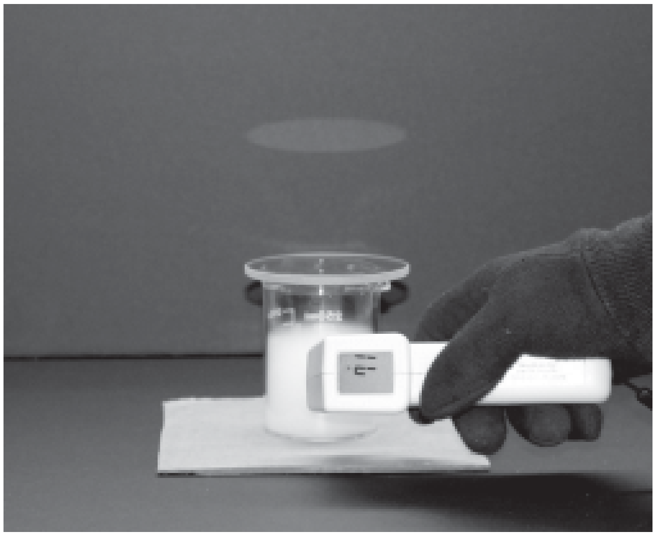

Figure 4. Use an infrared thermometer to determine the temperature of the container and surroundings. Allow the container to rest until temperatures are equal.

Use an infrared thermometer to compare the temperature of the beaker and lid to the surrounding temperature (Figure 4), including the surface on which the beaker is resting. If the surface supporting the beaker is not the same temperature as the beaker you may need to place an insulator such as a towel or cardboard between them. Do not use your hand without an insulating glove to hold the beaker as it will cause an increase in the temperature of the beaker and sample. Evaporating liquids will cool the bottom of the container slightly. Injecting fume from the air current tube will warm the contents slightly. Allow the temperature of the beaker and contents to stabilize.

In still air, gently lift the beaker and remove the lid by gently sliding the lid horizontally away from the beaker. Lighter than air gases and vapors will begin to rise from the beaker along with some of the white "smoke." Heavier than air gases and vapors will rest within the beaker, although any slight air movement can draw some fume from within the top of the beaker. Gently turn the beaker almost ninety degrees (tilting less than ninety degrees will prevent spilling any liquid sample remaining in the beaker) so the opening is

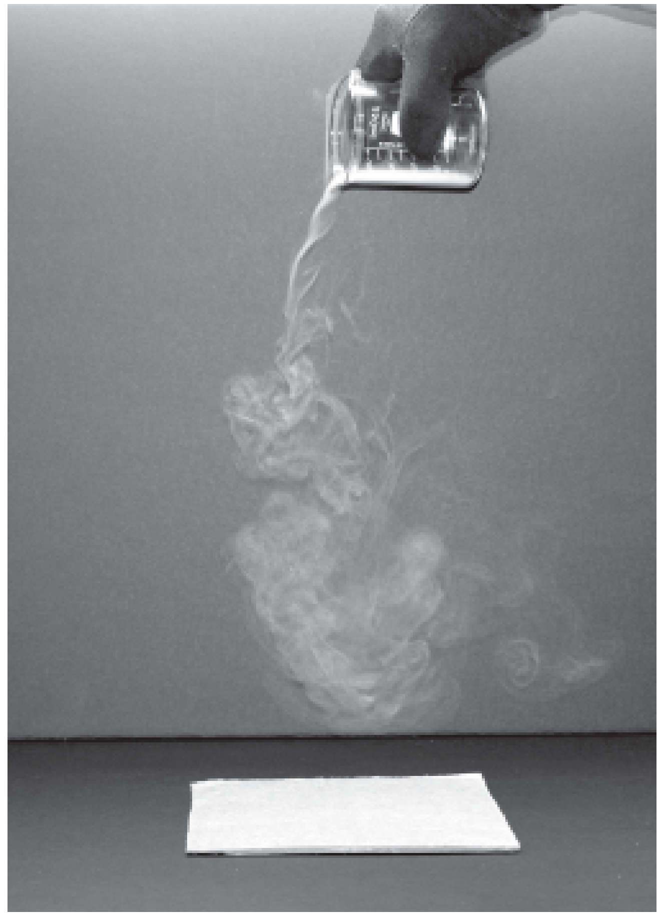

Figure 5. Tilt the beaker almost ninety degrees and observe the flow of the fume and vapor.

perpendicular to the floor and observe the movement of the white fume (Figure 5). Slightly denser than air vapors and gases will move downward in a slow, tumbling movement. Very dense vapors and gases will appear to plummet; some may continue down to the bench top and spread laterally. Relative density of the sample can be estimated based on your experience with known samples.

Several images follow that describe the density of a gas or vapor retlaive to ambient air. Standard vapor density values are included from references.

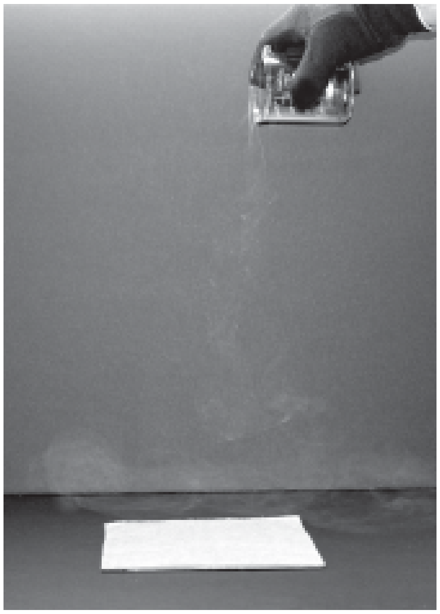

Figure 6. Trichloroethylene vapor (vapor density 4.5) remains in the beaker when the lid is removed and falls rapidly when the beaker is tipped.

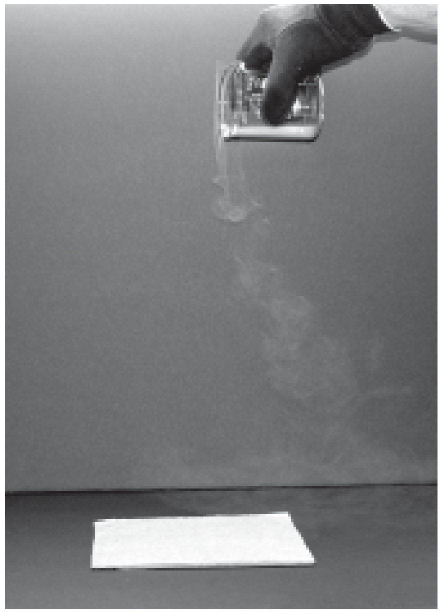

Figure 7. 1,1,1,2-tetrafluoroethane has a vapor density of 3.6 and falls rapidly but does not plummet as quickly as the trichloroethylene in Figure 6.

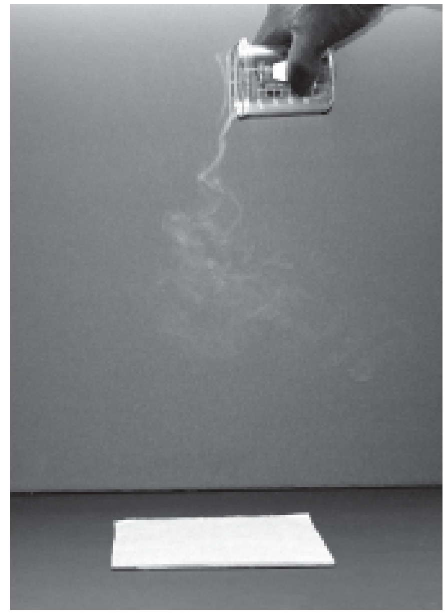

Figure 8. Hexane has a vapor density of 3.0 and drifts downward with less energy than heavier vapors. This sample contains only atmospheric moisture. Compare to the image of isopropyl alcohol in Figure 9.

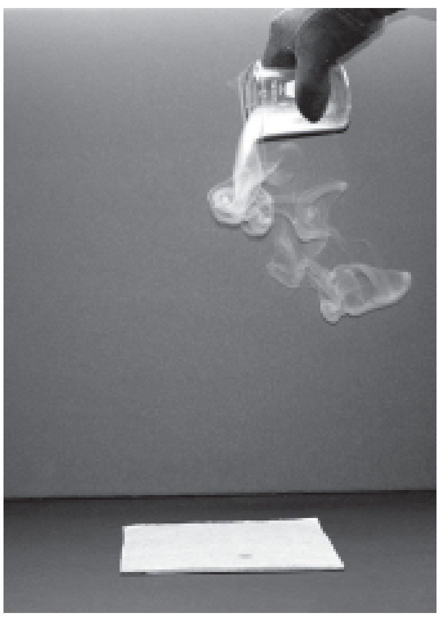

Figure 9. Isopropyl alcohol, 91%, contains water and produces a denser fume. The vapor density of isopropyl alcohol is 2.1 and the vapor density of moist air is less than dry air. This test measures the net buoyancy of the sample vapor and fume in air. Compare to hexane image with a lesser water content in Figure 9.

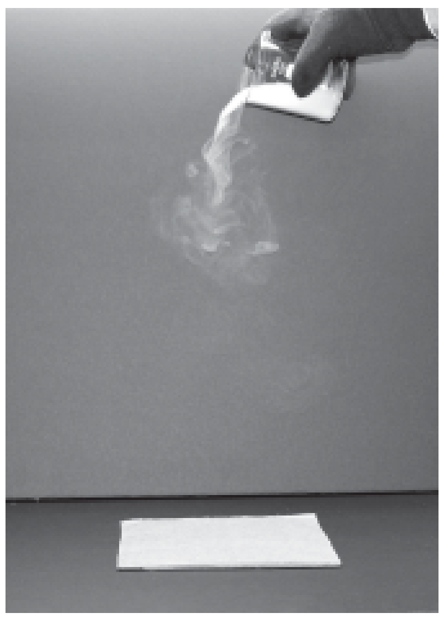

Figure 10. Starter fluid is a mixture of carbon dioxide (vapor density 1.53), ethyl ether (vapor density 2.6) and heptane (vapor density 3.5). The material safety data sheet for this product describes the vapor density only as "heavier than air." This test can be used to determine relative vapor density of mixtures in air.

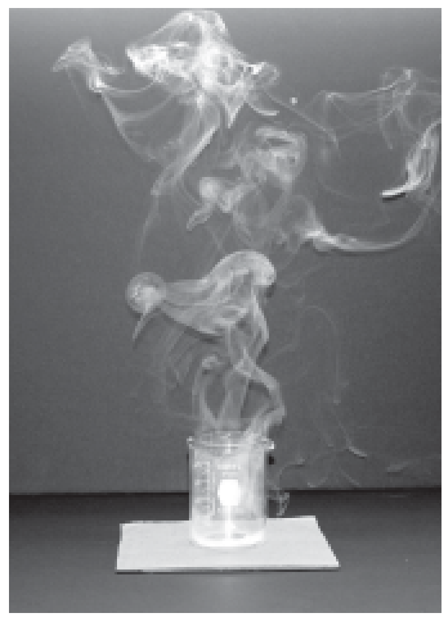

Figure 11. Ammonium hydroxide vapor and air current tube fume rise immediately upon removal of the lid. Ammonia has a vapor density 0.6 but dissolves into water vapor that also has a lighter-than-air vapor density.

Estimating Vapor Solubility

You can estimate the relative water solubility of a vapor or gas by using the same air flow “smoke” tubes for estimating vapor density. Prepare a sample as described for estimating vapor density and observe the visual density of the fume in the sample while it is covered and still resting.

A sample with higher moisture content will produce a “thicker” or more opaque cloud when either the Sensidyne or Drager air current tube is used. For example, one pump of fume injected into trichloroethylene vapor will appear to be “thin” while one pump of fume into a sample of 91% isopropyl alcohol (9% water) vapor will appear to be “thick.” Low humidity samples, such as hexane vapor, may contain fume that is not visible until making contact with atmospheric moisture when the sample is spilled from the beaker.

The visual density of the fume inside the sample beaker can give you a relative idea of the water solubility of the vapor or gas. Samples that immediately produce a thick white fume in the beaker most likely already contain water and are likely to be fairly water soluble. Samples that hold a thin, lightly visible white fume contain little water vapor and the vapor or gas is displacing humid air from the beaker. The visual fume density of anhydrous samples may increase once the vapor is released from the beaker and mixes with humid air. You can use this estimate of the water solubility of the vapor or gas to determine how effective water spray might be in absorbing or scrubbing vapors from the air. Water soluble gases and vapors tend to cause injury to the upper respiratory system due to early entrapment by moist membranes in the upper airway. Water insoluble gases and vapors tend to cause injury deep in the lungs due to the inability of the moist upper airway membranes to absorb the gas or vapor. Obviously, an unknown material can cause other types of injury by being absorbed and transported throughout the body.

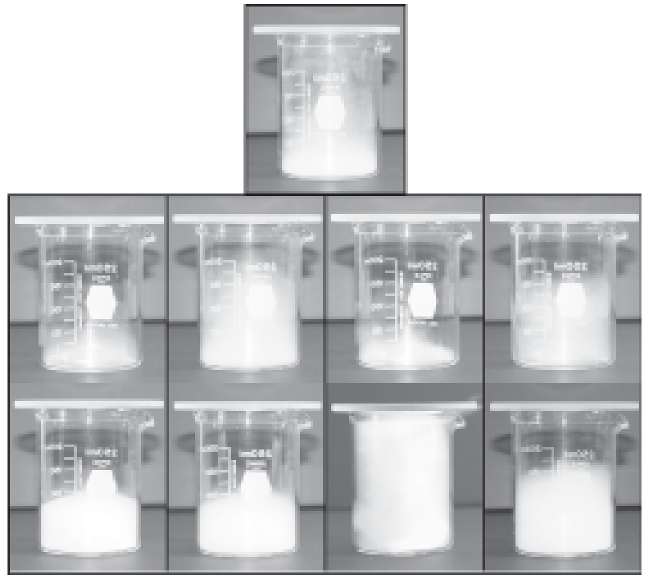

Figure 12. The relative water vapor content and the relative water solubility of the vapor or gas can be estimated by the visual density of the fume. Samples are described from left to right with water solubility values. Top row: room air and ambient humidity. Middle row: hexane (0.002%), propane (0.01%), trichloroethylene (0.1%), 1,1,1,2-tetrafluoroethane (0.1%). Bottom row: 91% isopropyl alcohol, (miscible), acetone (miscible), ammonium hydroxide (soluble), glacial acetic acid (miscible). The bottom row illustrates the higher water content of water soluble vapors. The middle row has had much of the room air displaced by insoluble vapors or gas. An exception is propane (second from left), which was injected into the beaker with a propane torch head. The torch head mixes room air with the propane in a proper proportion to support the torch flame; therefore the propane sample contains a higher proportion of room air and humidity than the other samples in the middle row.

It might be possible that an unknown anhydrous sample could react with the smoke tube reagents to form a fume, so do not use this test as a firm indicator of the water content. In fact, you should never rely on a single test as a sole source of information on which to plan a response. Figure 12 shows the density of fume produced by a Sensidyne Tube 5100 Smoke Tube (Air Flow Indicator Tube) for several samples along with the solubility of the liquid in water.

References

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